SLD MODELING WITH CANICE

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OUTLINE

- Introduction
- Physics of SLD
- The CANICE Codes
  - Prediction capabilities
  - Methodology
- SLD Modeling with CANICE
  - Results
  - Discussion
- Future Work
- Conclusions

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Introduction

- Major aircraft crashes because of SLD
  - October 1994, Roselawn, Indiana : ATR-72 commuter aircraft
  - January 1997,Detroit : Embraer 120 twin engine turbo- prop aircraft

- Primary objective of the recent Canadian aircraft in-flight icing research
  - Characterize the icing environment with SLD
  - Develop better technique for forecasting

Introduction

- 80% of the SLD observed in-flight near St.John's and Ottawa*.
- SLD encounter occurred 73% of the time during flight in icing conditions near St. John's and 41% near Ottawa*.
- FAR-25C envelope was exceeded with MedVD greater than 50e-6 m*.

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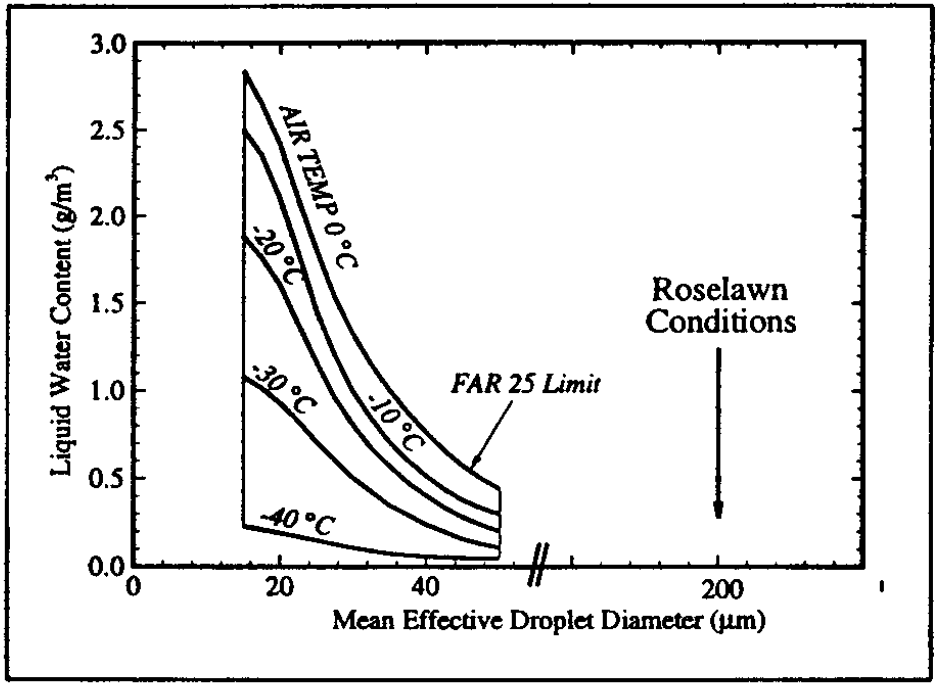
*G.A. Isaac *et al.*, 2001

Physics of SLD

- Intermittent maximum atmospheric icing conditions, FAR 25 appendix C



- Max Droplet size for certification=50e-6 m
- Droplets with diameter more than the envelope limit called Supercoold Large Droplet (SLD)

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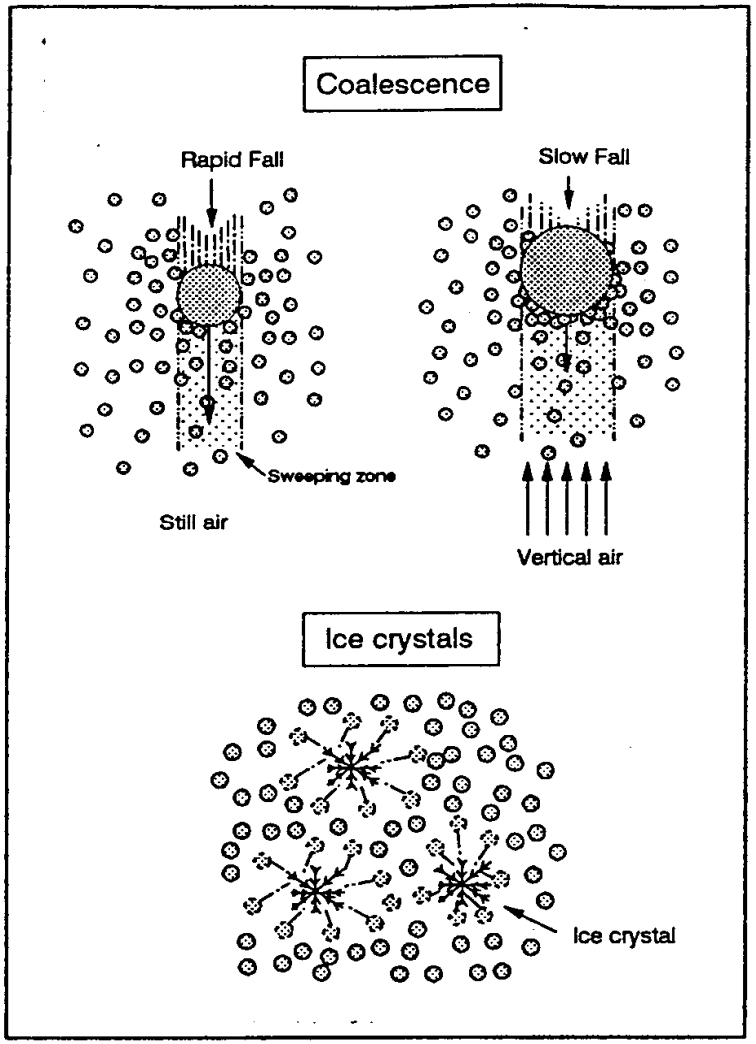
Physics of SLD

- Cloud Droplet Growth

1. **Coalescence because of different fall velocities**

2. **Growth of ice crystals due to coexistence side by side of both ice crystals and cloud droplets**



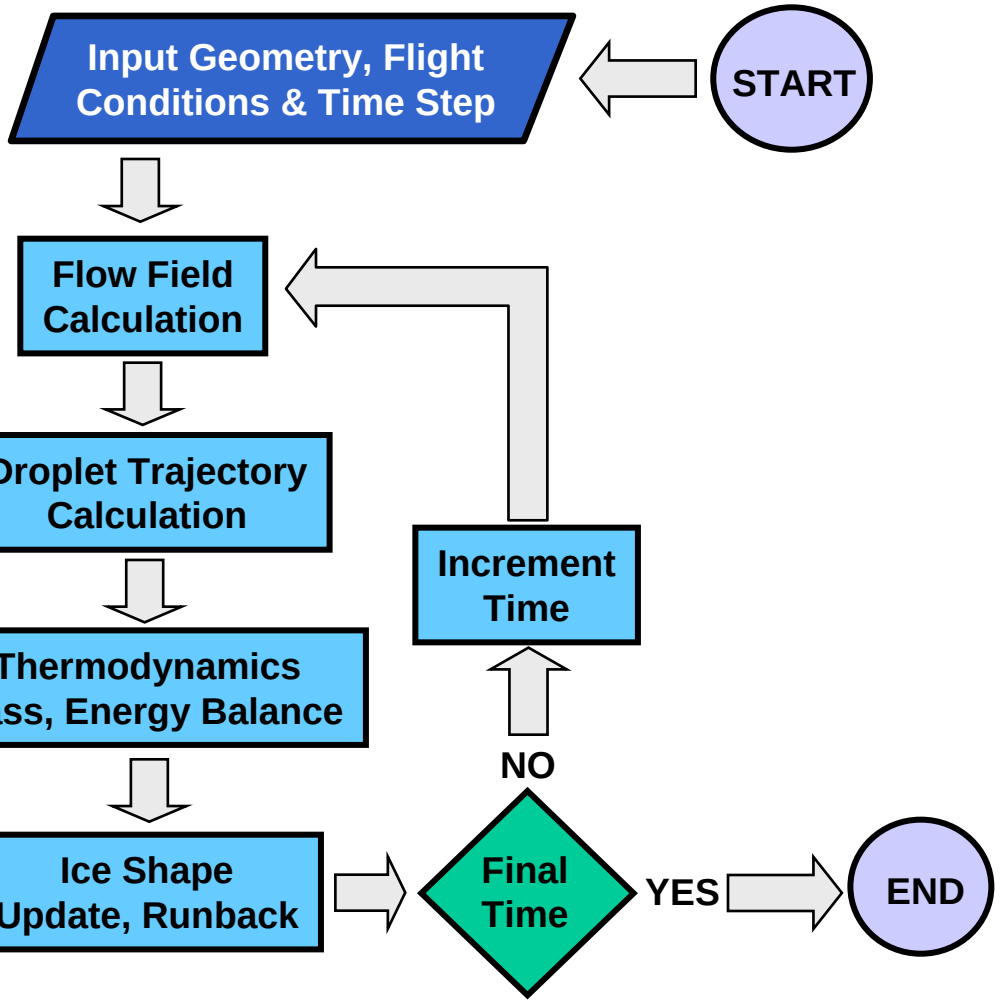
THE CANICE CODE ...

- A Planned development/modification of the CANICE code
  - CANICE-2D v3.1 (multi-element capability + anti-icing simulation)
  - CANICE-3D v1.3 (a panel method based full aircraft ice accretion prediction code)
- Prediction Capabilities
  - Rime & glaze ice accretions on airfoils & wings (2D & 3D)
  - Aerodynamic performance degradation (2D & 3D)
  - Rime & glaze ice on multi-element configurations (2D)
  - Hot-air anti-icing simulation (2D & 3D)

THE CANICE CODE ...

- Methodology

  CANICE 2D & CANICE 3D



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THE CANICE CODE ...

- CANICE - Code Description
  - Flow field module
    - Hess & Smith panel method for 2D multi-element configurations and CMARC panel code for 3D
  - Trajectory and water impingement module
    - Lagrangian approach using a 4th order Runge-Kutta scheme
    - Water-droplet impingement characteristics, local & global water-catch efficiencies

THE CANICE CODE ...

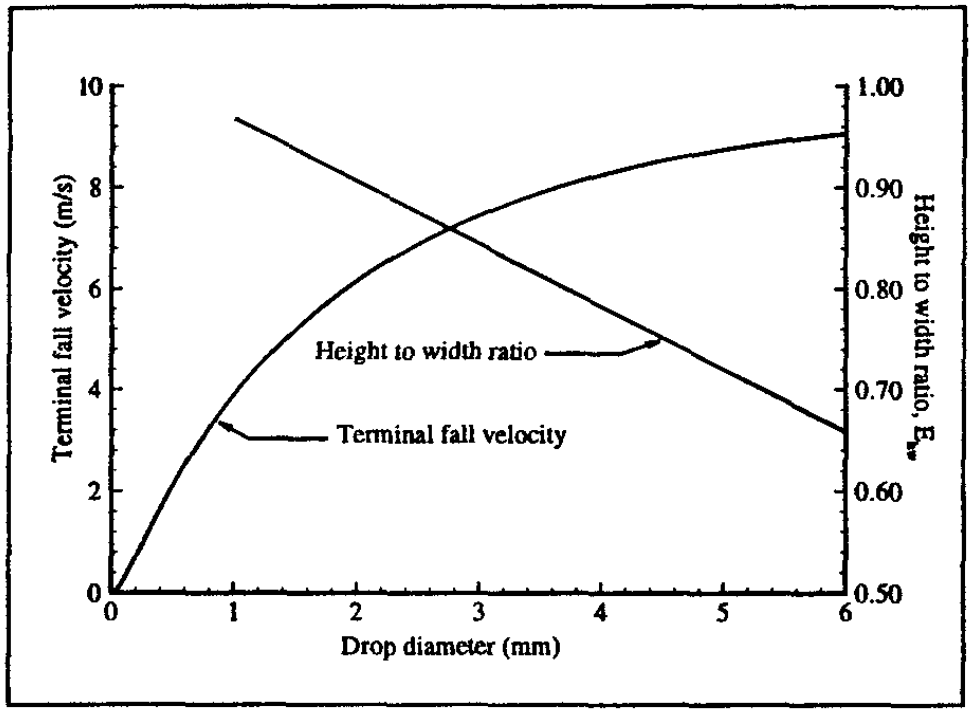
- CANICE - Code Description ...
  - Thermodynamics module
    - Mass and energy balance relations are solved for surface temperature and freezing fraction
    - Includes Boundary–layer with roughness model
  - Geometry update/smoothing module
    - Smoothing of the ice catch through a simple mass averaging technique across adjacent panels
  - Hot-air module
    - Numerical correlation for hot-air jet impinging on a curved surface

SLD Modeling

SLD characteristics included in CANICE (2D & 3D)

- Droplet terminal fall velocity
- Droplet drag coefficient (for large and deformed drops)
- Droplet release position - starting point for the integration of its trajectory (function of drop's weight)

SLD Modeling – characteristics included in CANICE



Droplet terminal fall velocity

$$V_T = \left[\frac{4 d_d (\rho_d - \rho_a) g}{3 \rho_a C_D}\right]^{\frac{1}{2}}$$

$$N_D = C_D Re^2 = \frac{4}{3}\frac{d_d^3 \rho_a (\rho_d - \rho_a) g}{\mu_a^2}$$

$$E_{hw} = 1.030 - 0.062\, d_d$$

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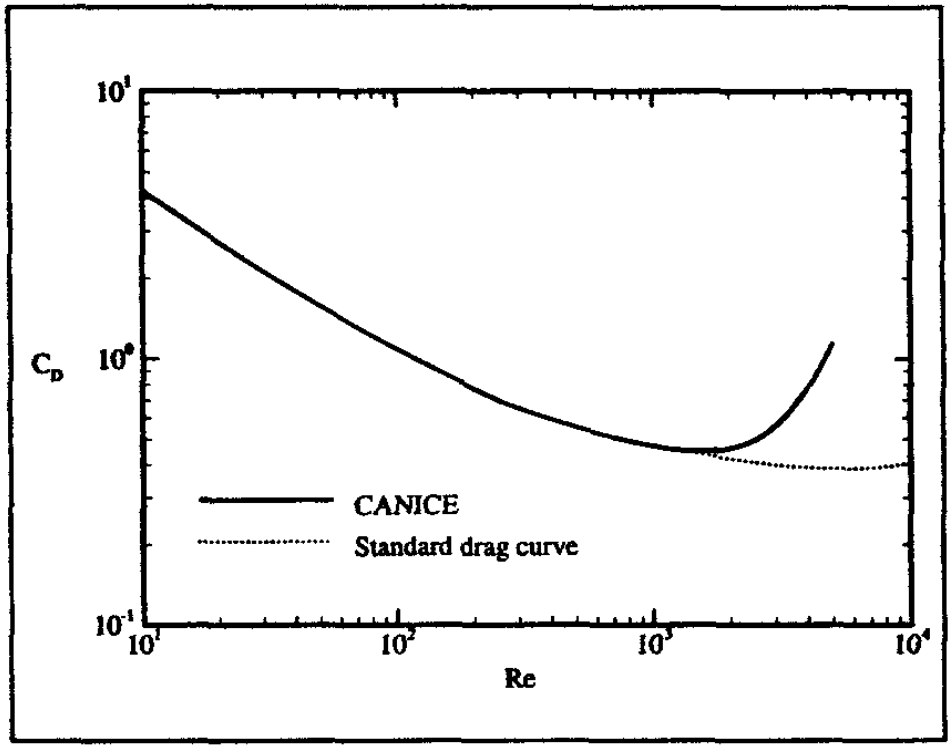
SLD Modeling – characteristics included in CANICE



Droplet drag coefficient

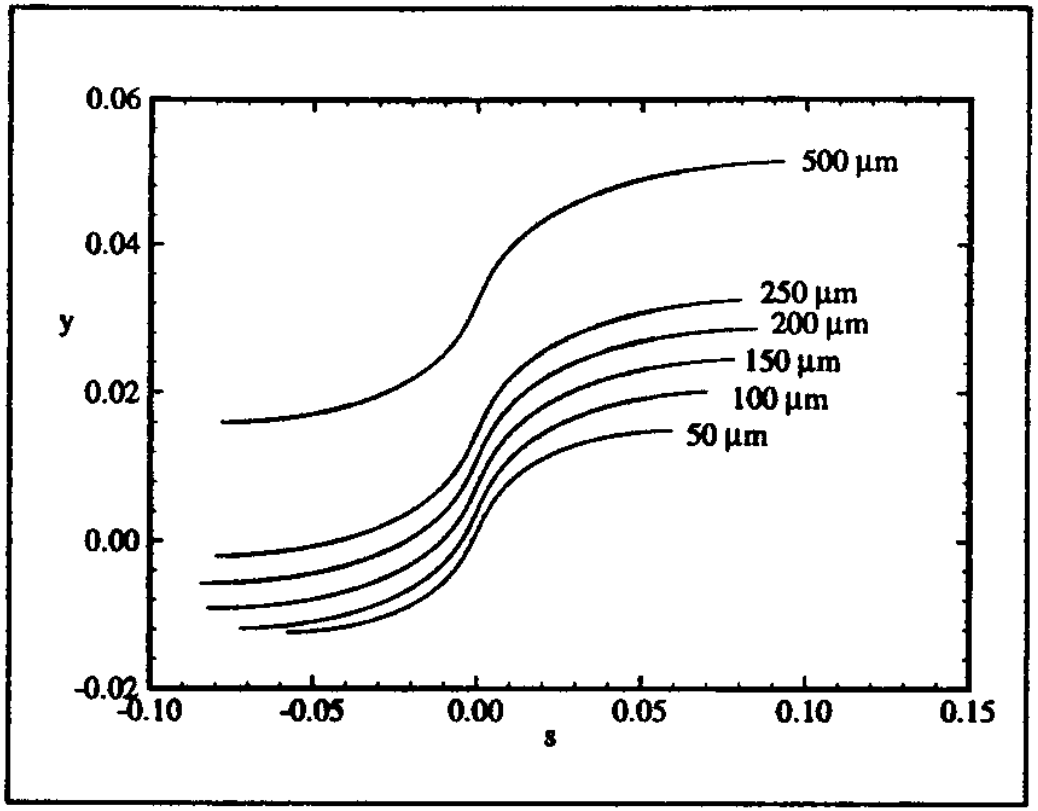
Khan and Richardson

$$C_D = \left(2.25\,\mathrm{Re}^{-0.31} + 0.36\,\mathrm{Re}^{0.06}\right)^{3.45}$$

$0.01 < \mathrm{Re} < 3.10^5$

SLD Modeling – characteristics included in CANICE

Droplet release position



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SLD Modeling

- Assessment of CANICE's Performance
  - The 2D & 3D versions of the code were used in all numerical simulations
  - The overall predictions were satisfactory
  - The numerical results provide evidence of its strengths and weaknesses
  - A plan to overcome its weaknesses has been laid out

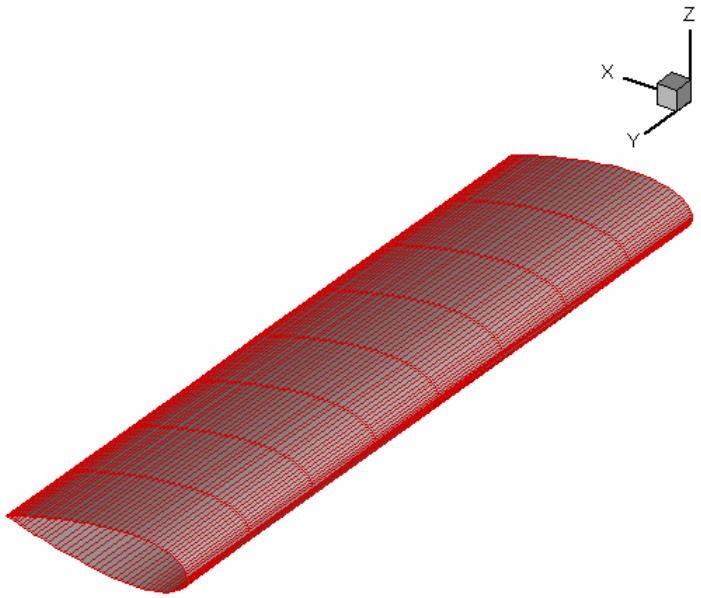
SLD Modeling – NACA 0012 airfoil / wing

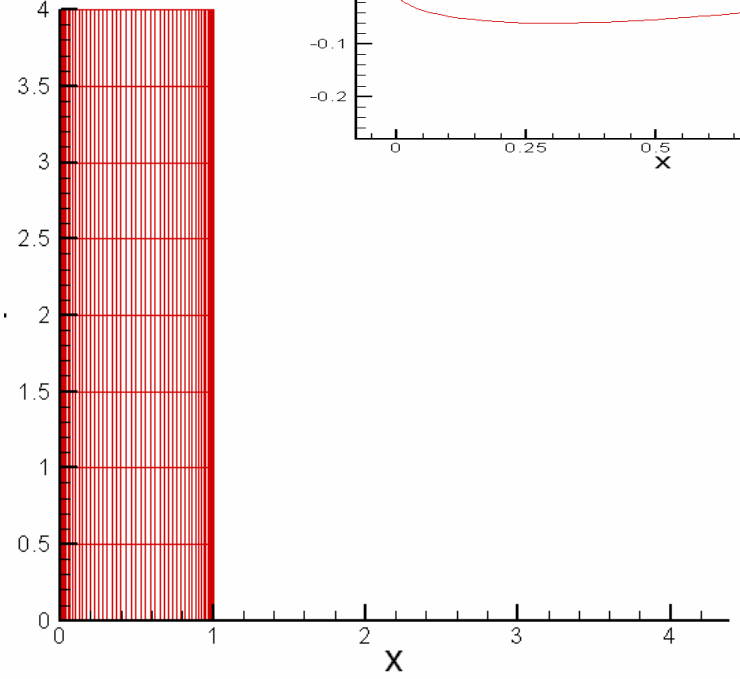
- **Effect of MVD on water collection efficiency**
  MVD= 20, 50, 100, 150, 200, 250, 500 μm
- **Effect of AOA on water collection efficiency**
  MVD=150μm , AOA = 0 , 8 deg.
- **Effect of MVD on ice shapes**
- **Effect of LWC on ice shapes**
- **Effect of AOA on ice shapes**
- **Effect of temperature on ice shapes**

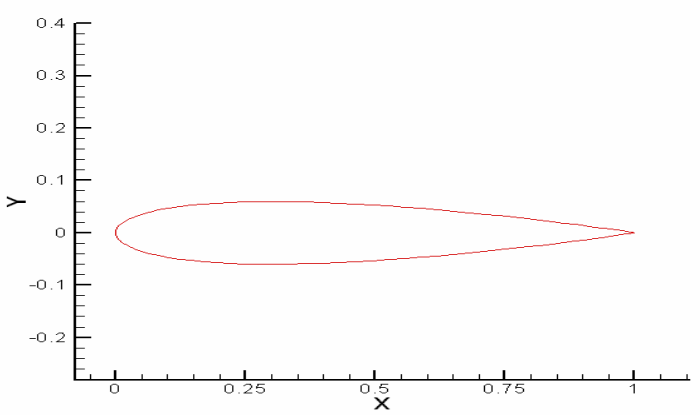
SLD Modeling

- **NACA 0012 airfoil / wing**

Chord=1 m AR=8 Panel No.=80x8







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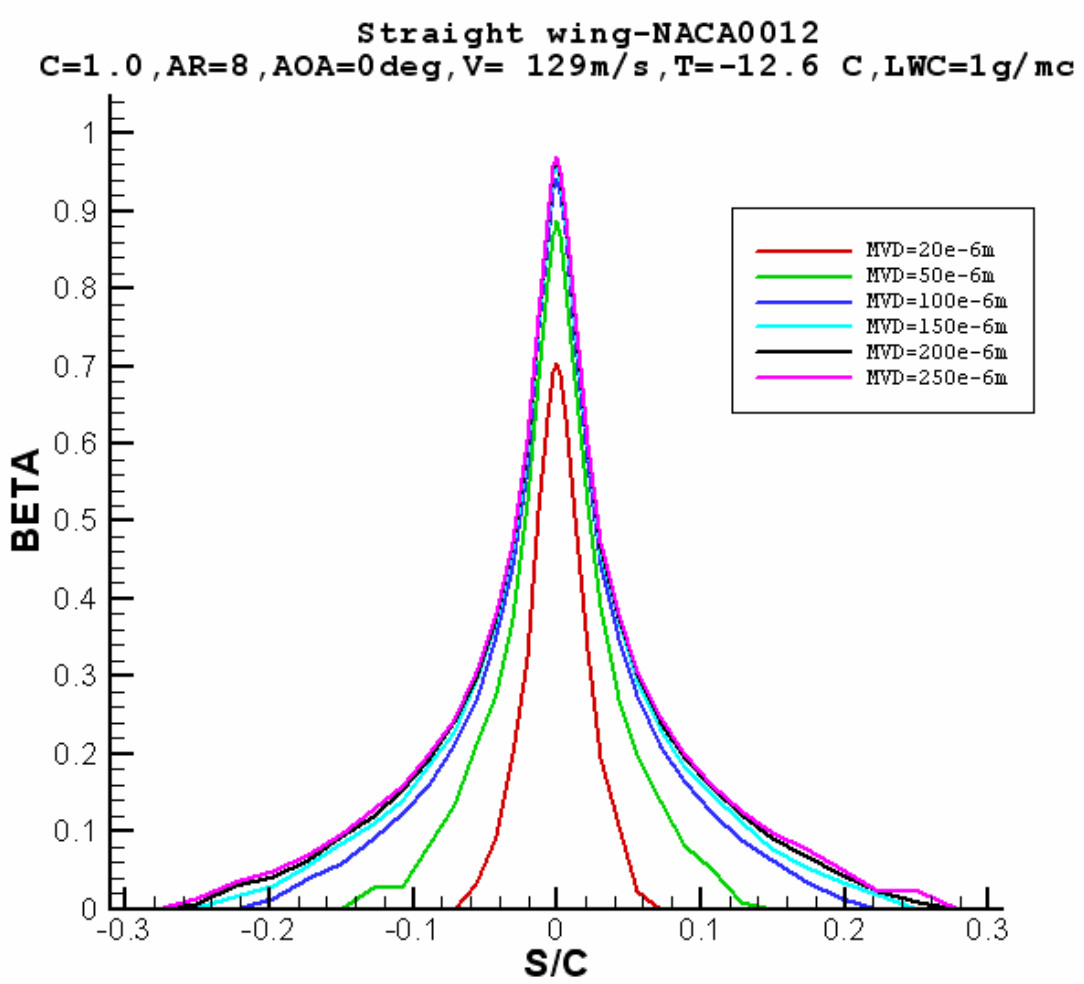
Results –NACA 0012 airfoil / wing

- Effect of MVD on water collection efficiency (CANICE 3D)

Y= mid. span



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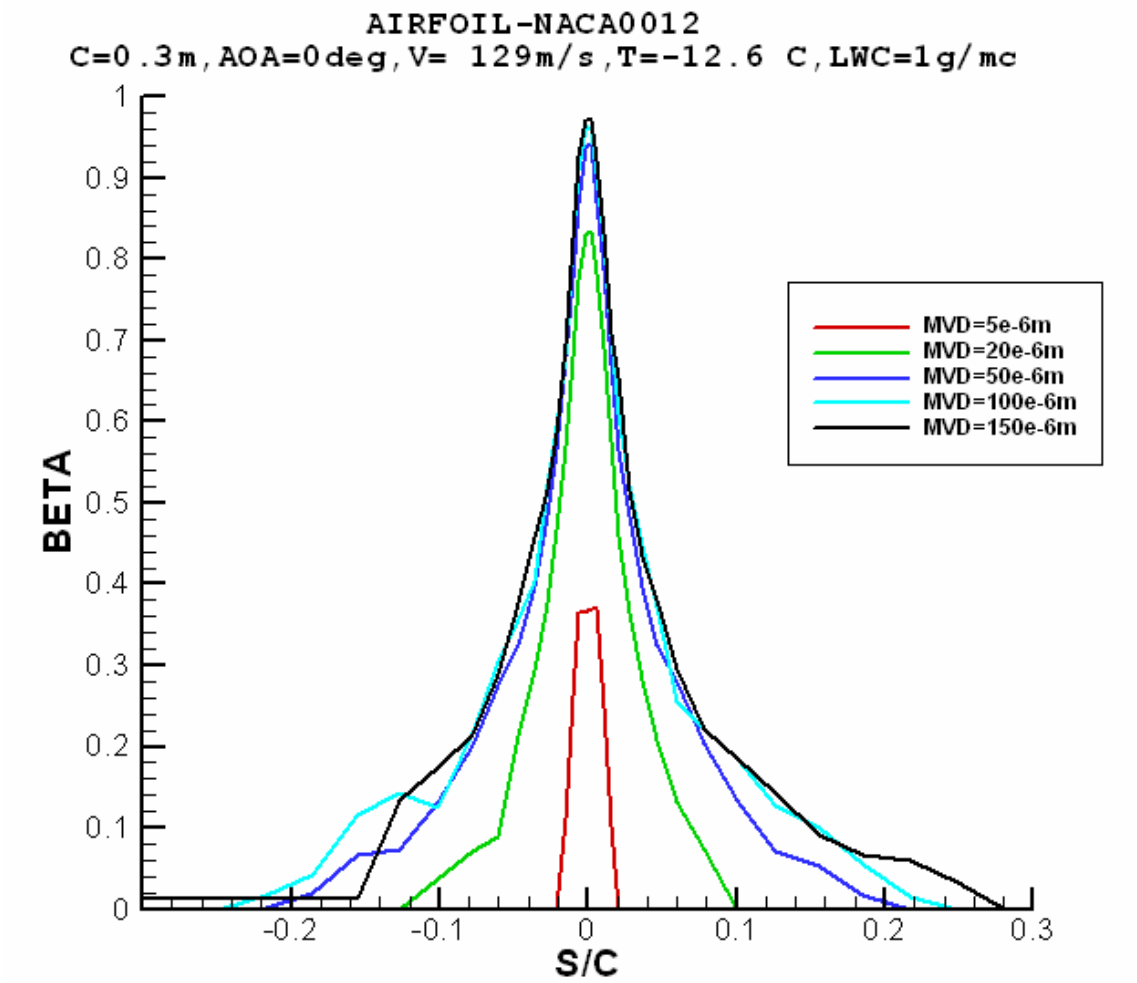
Results –NACA 0012 airfoil

- Effect of MVD on water collection efficiency (CANICE 2D)



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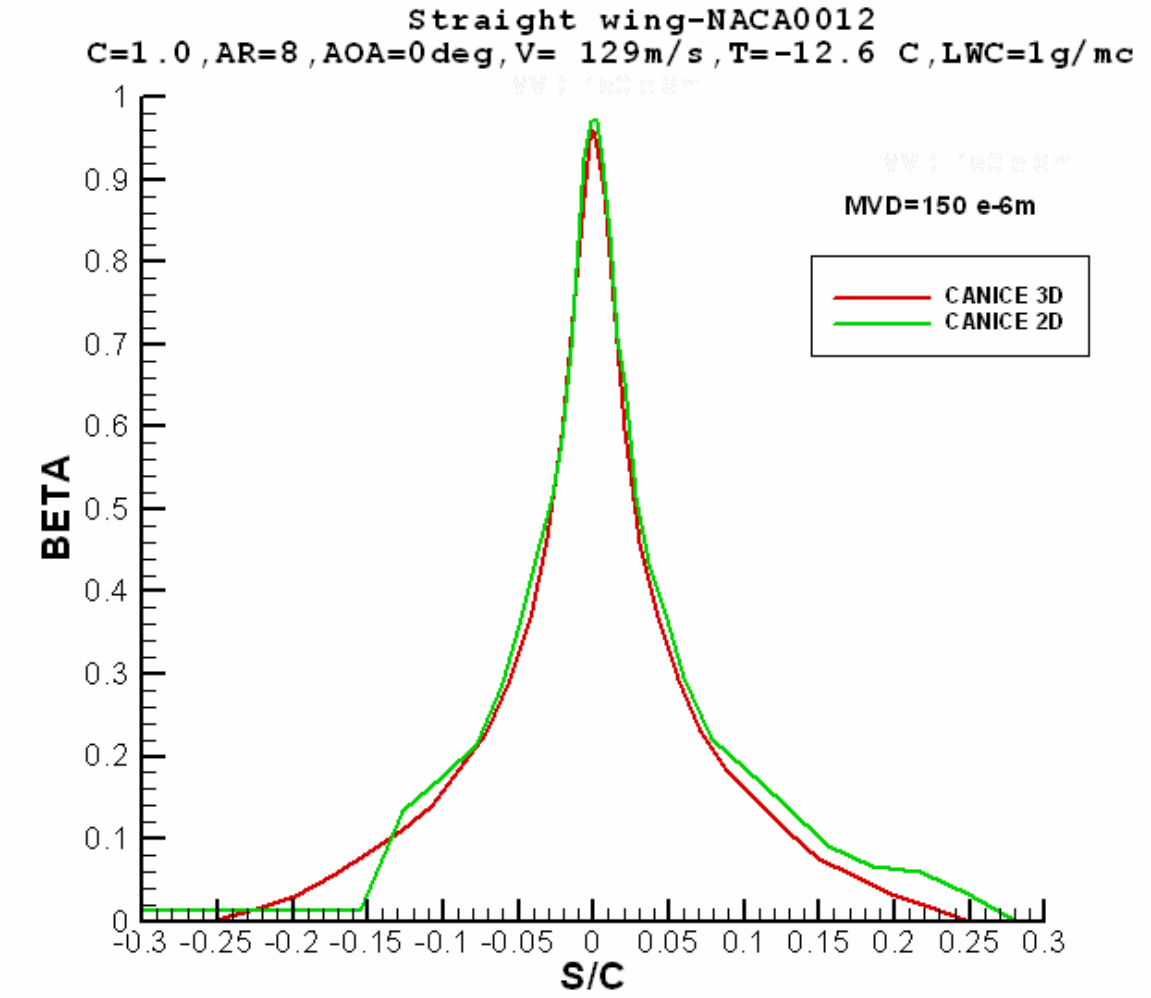
Results –NACA 0012 airfoil / wing

- Comparison of CANICE 3D & CANICE 2D Results

Y= mid. span



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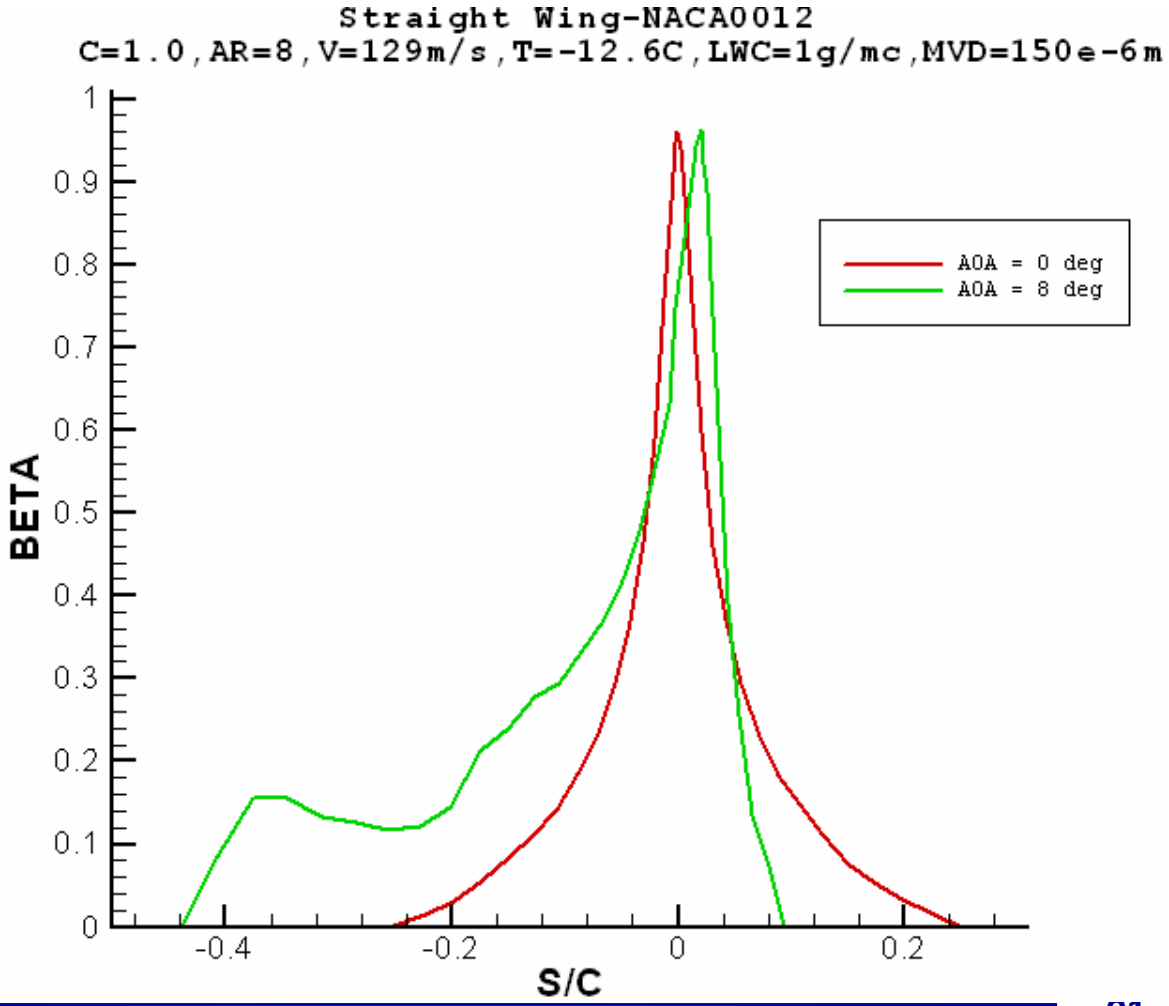
Results- NACA 0012 airfoil / wing

- Effect of AOA on water collection efficiency (CANICE 3D)

Y= mid. span



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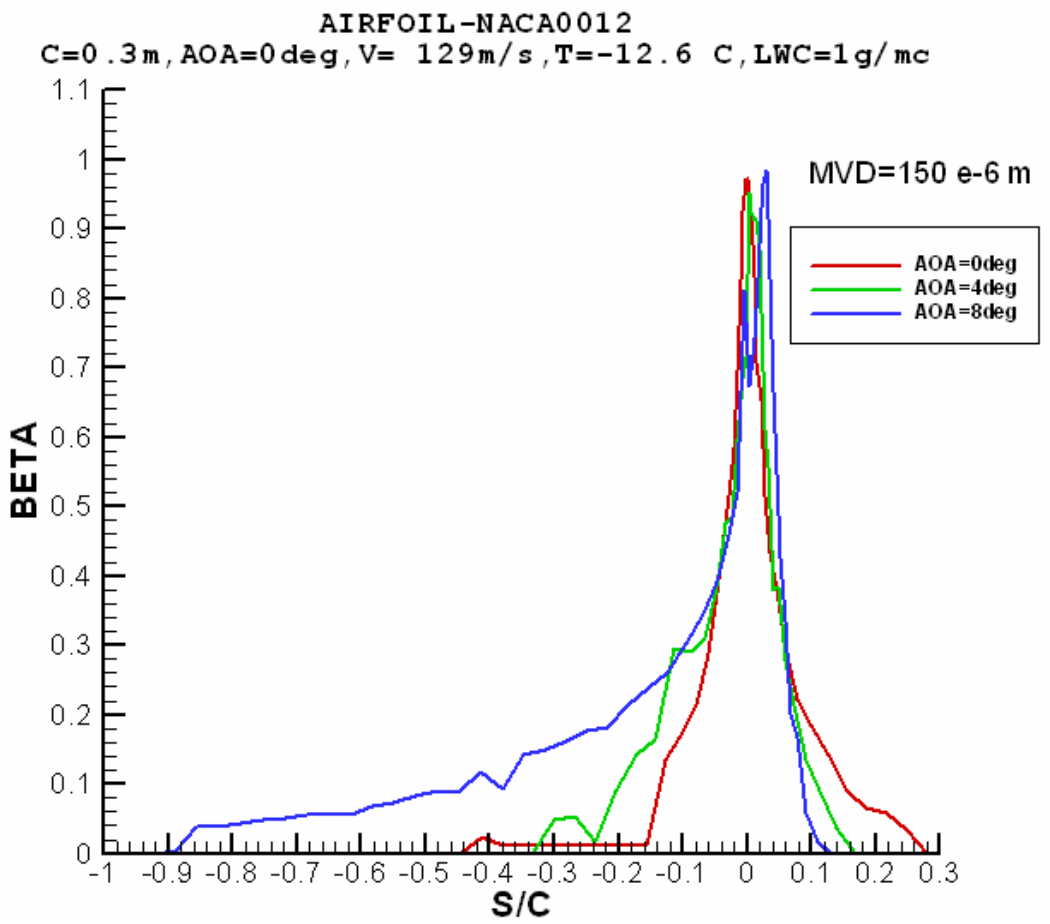
Results- NACA 0012 airfoil

- Effect of AOA on water collection efficiency (CANICE 2D)



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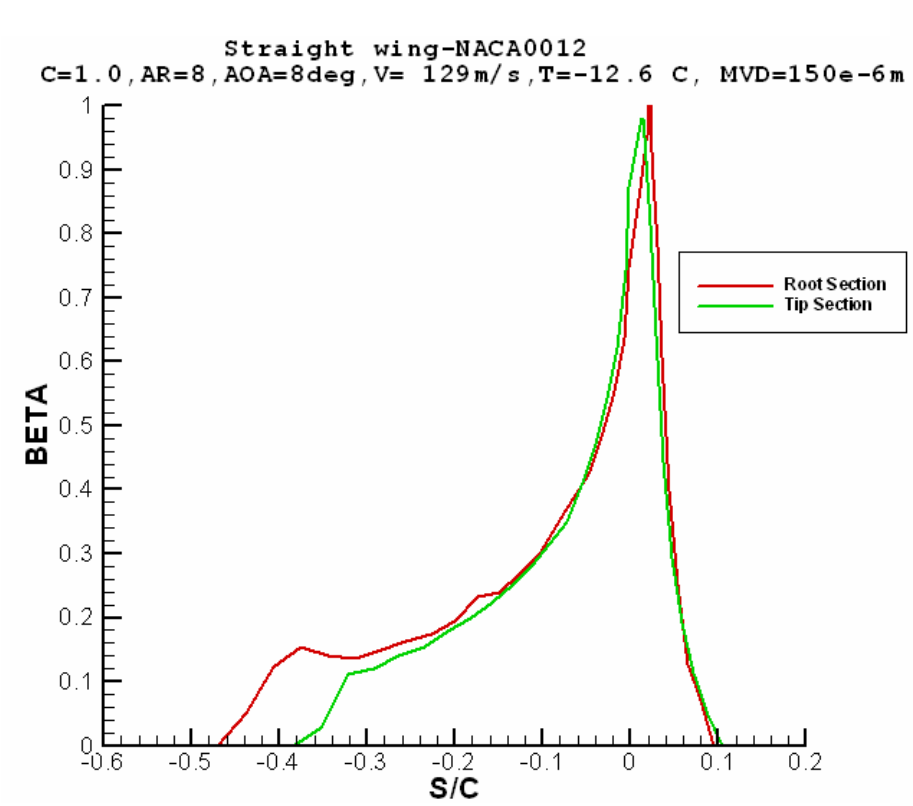
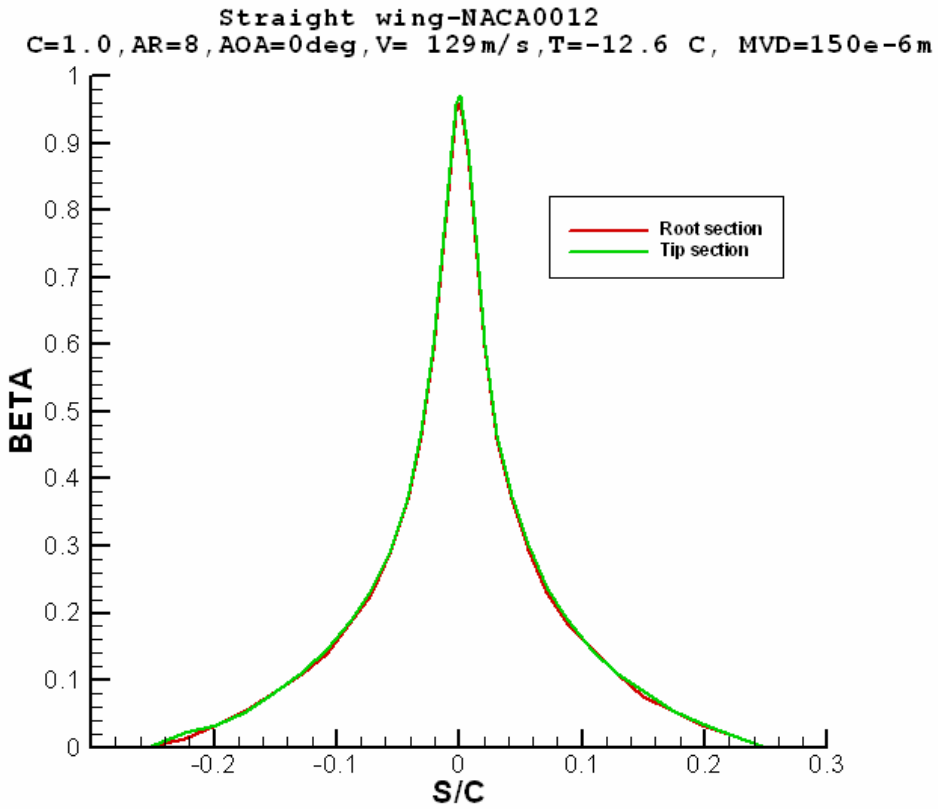
Results- NACA 0012 airfoil / wing

- Effect of finite span on water collection efficiency (CANICE 3D)





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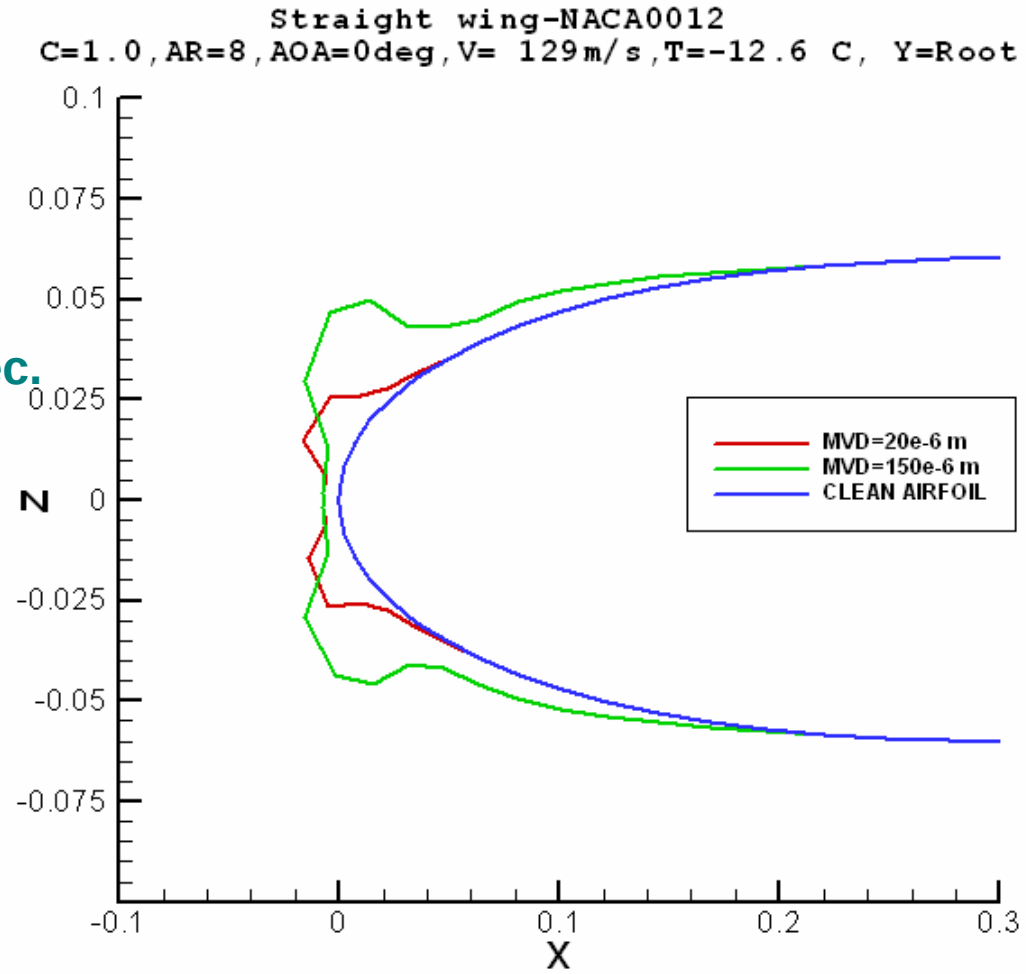
Results- NACA 0012 airfoil / wing

- **Effect of MVD on ice shapes (CANICE 3D)**

Ice Accretion time =120 Sec.
Ice layers = 3



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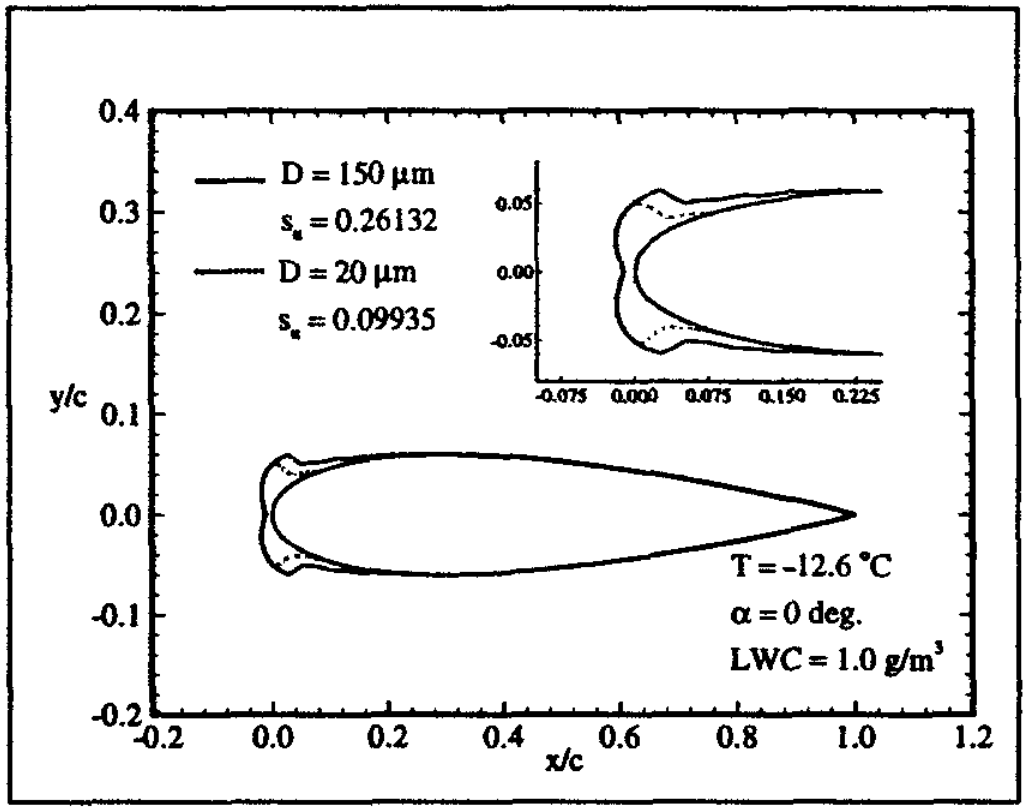
Results- NACA 0012 airfoil / wing

- Effect of MVD on ice shapes (CANICE 2D)

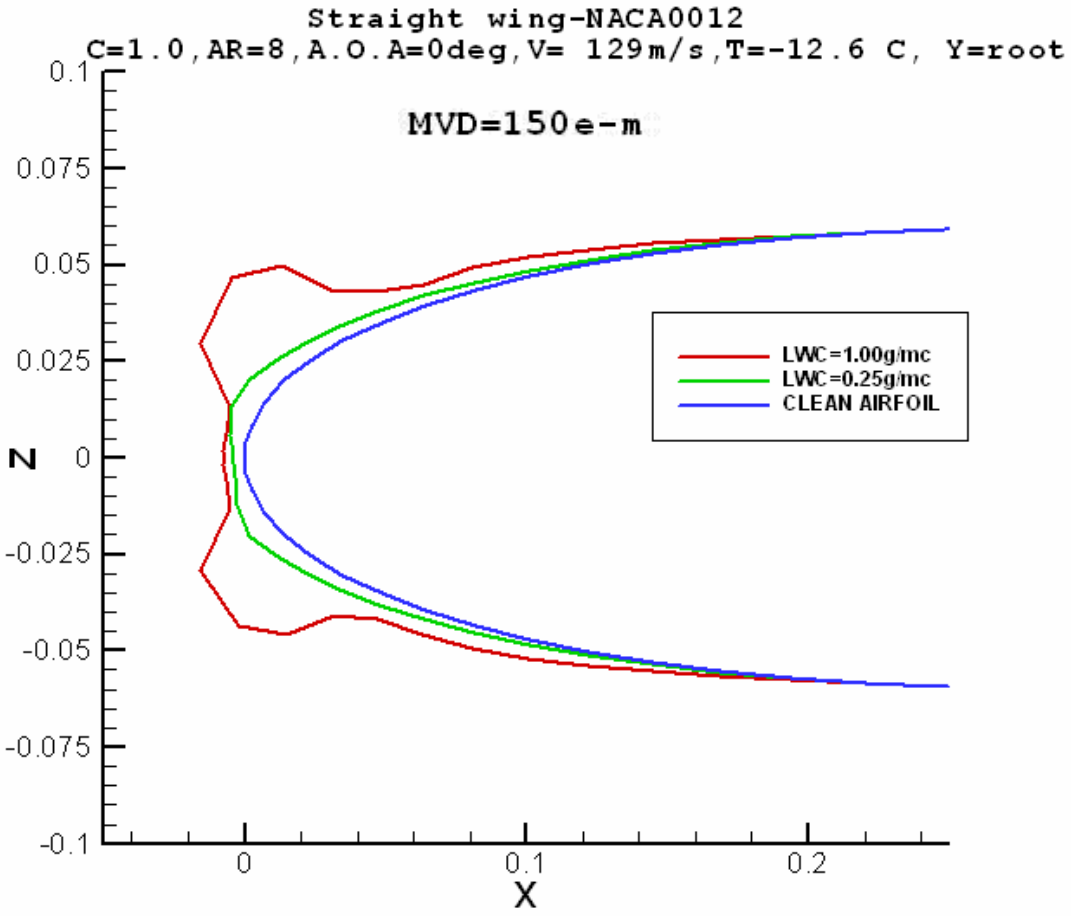
Ice Accretion time =120 Sec.
Ice layers = 3



Results- NACA0012 airfoil / wing

- Effect of LWC on ice shapes (CANICE 3D)

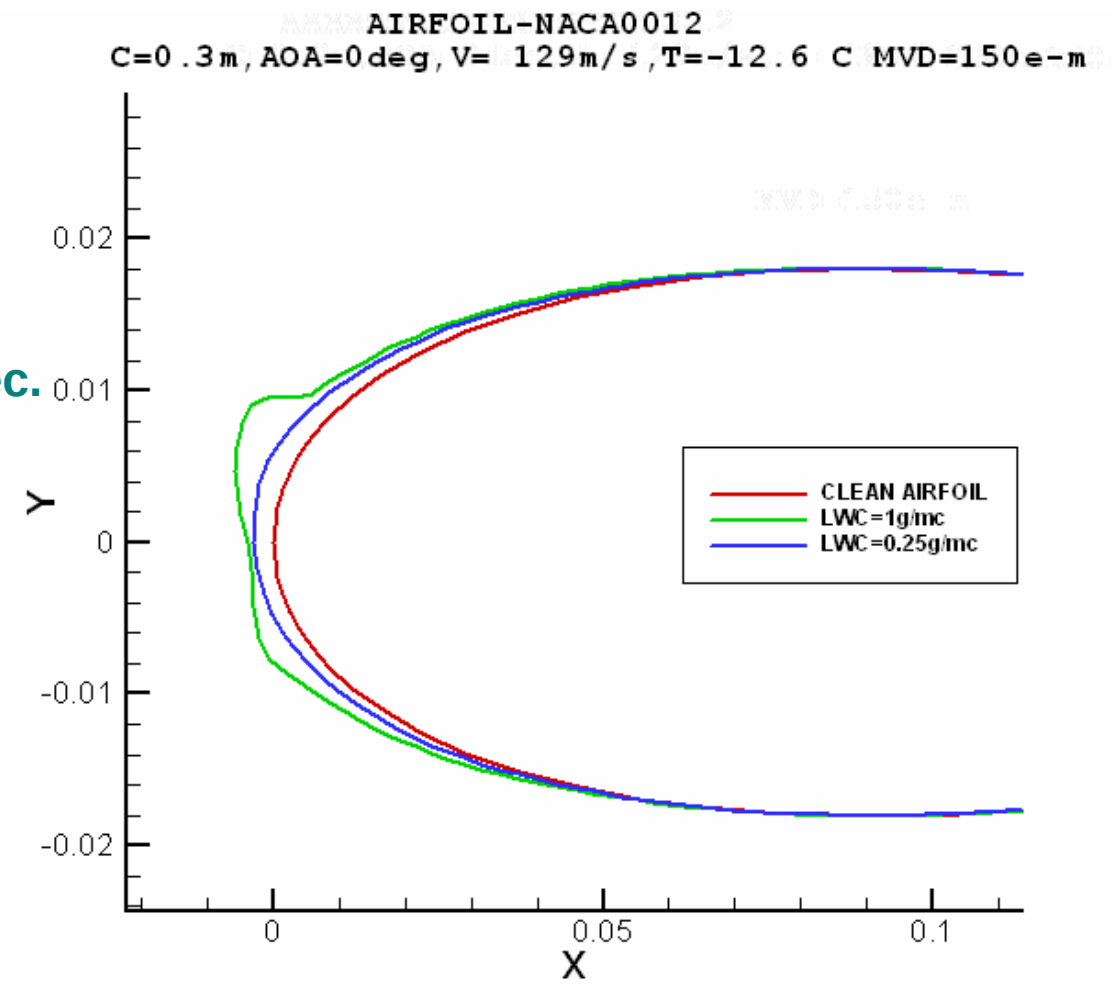
Ice Accretion time =120 Sec.
Ice layers = 3



Results- NACA0012 airfoil

- Effect of LWC on ice shapes (CANICE 2D)

Ice Accretion time =120 Sec.
Ice layers = 3



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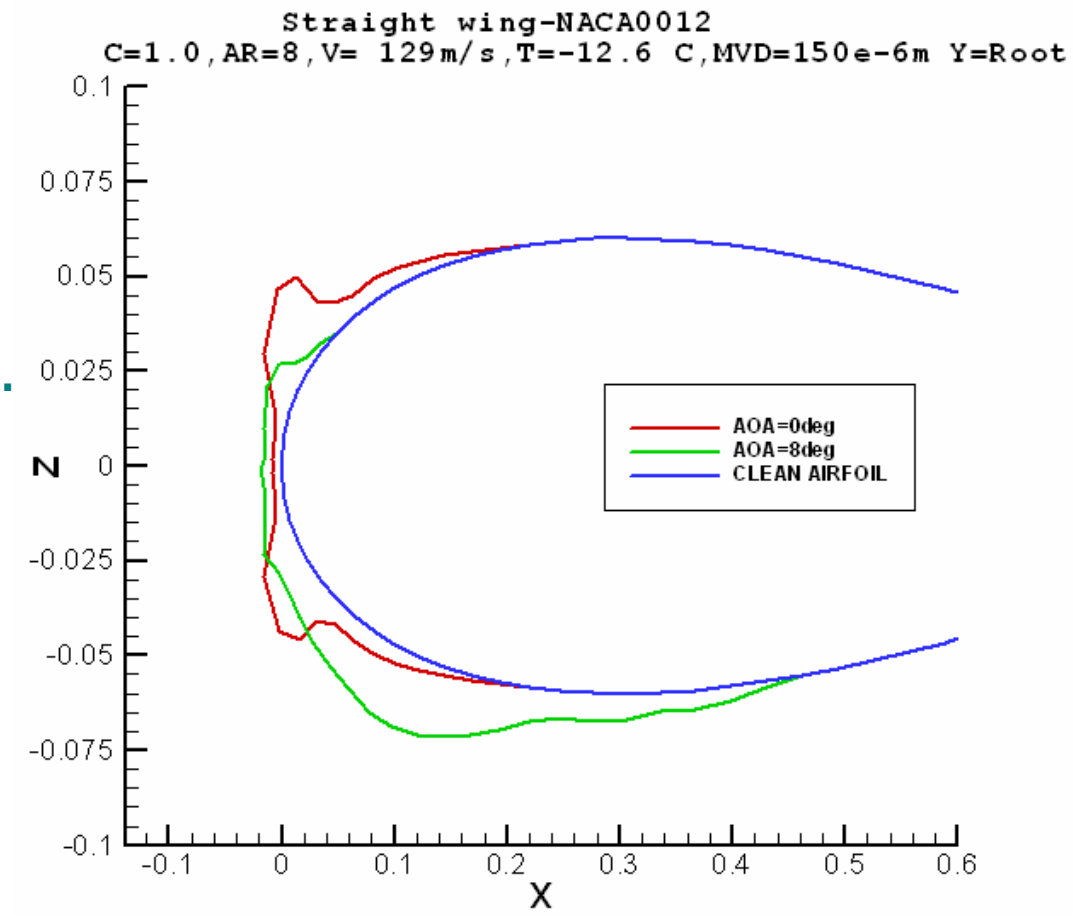
Results- NACA0012 airfoil / wing

- Effect of AOA on ice shapes (CANICE 3D)

Ice Accretion time =120 Sec.
Ice layers = 3



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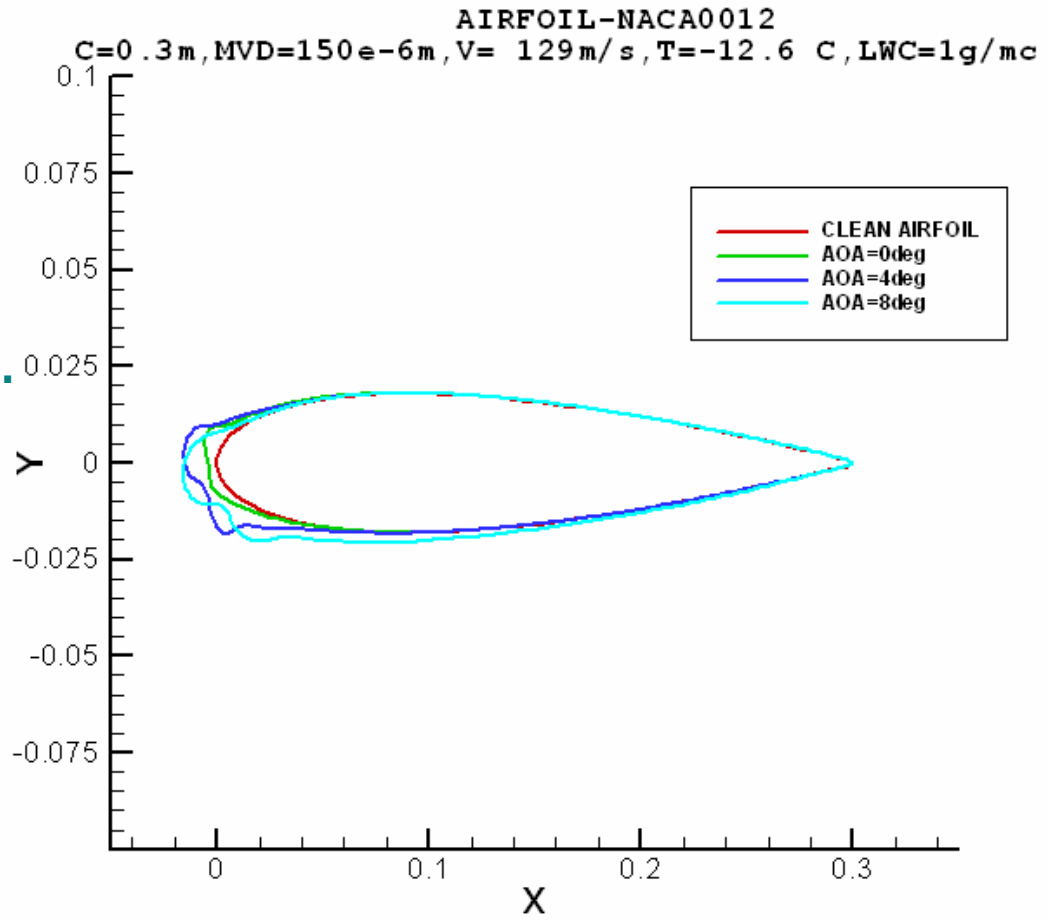
Results- NACA0012 airfoil

- Effect of AOA on ice shapes (CANICE 2D)

Ice Accretion time =120 Sec.
Ice layers = 3



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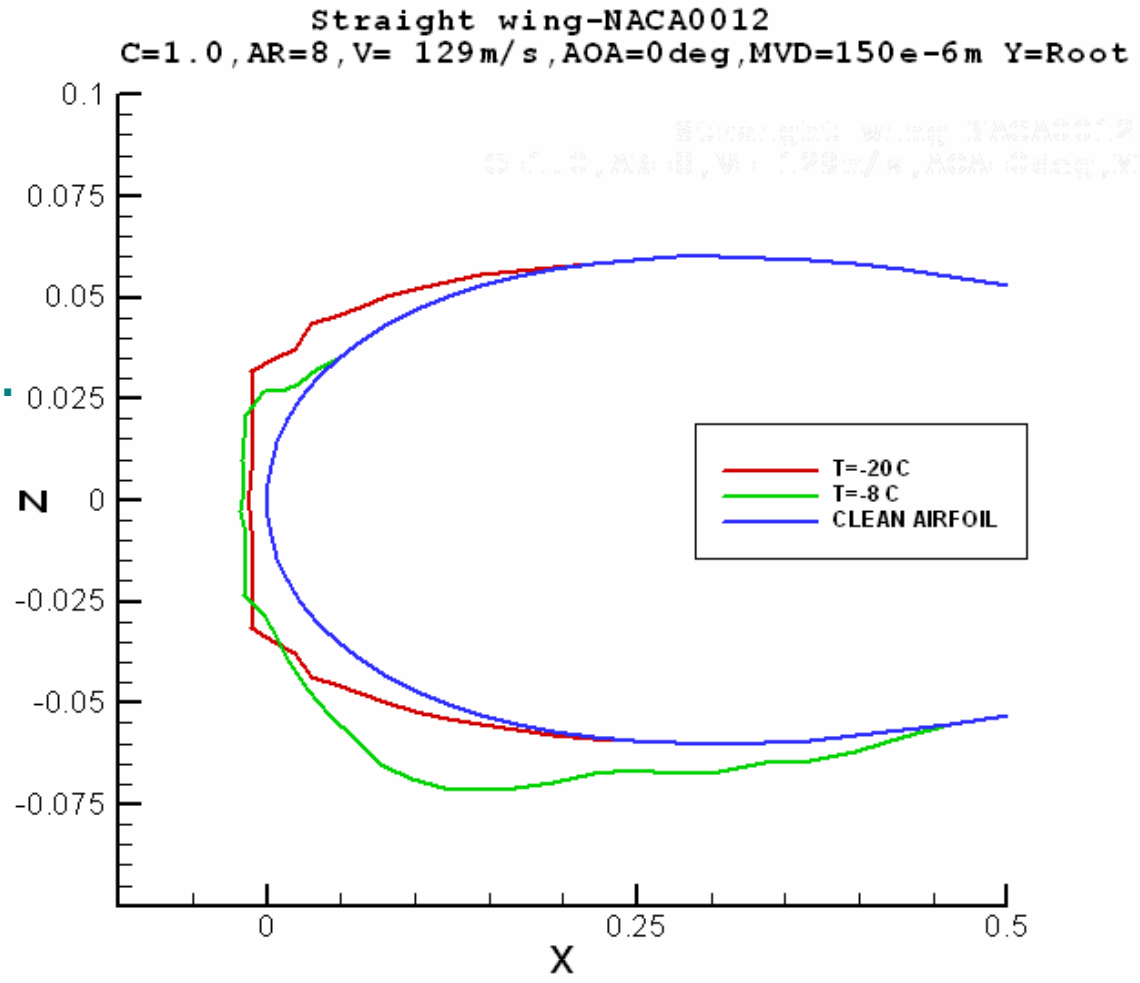
Results- NACA0012 airfoil / wing

- Effect of temperature on ice shapes (CANICE 3D)

Ice Accretion time =120 Sec.
Ice layers = 3



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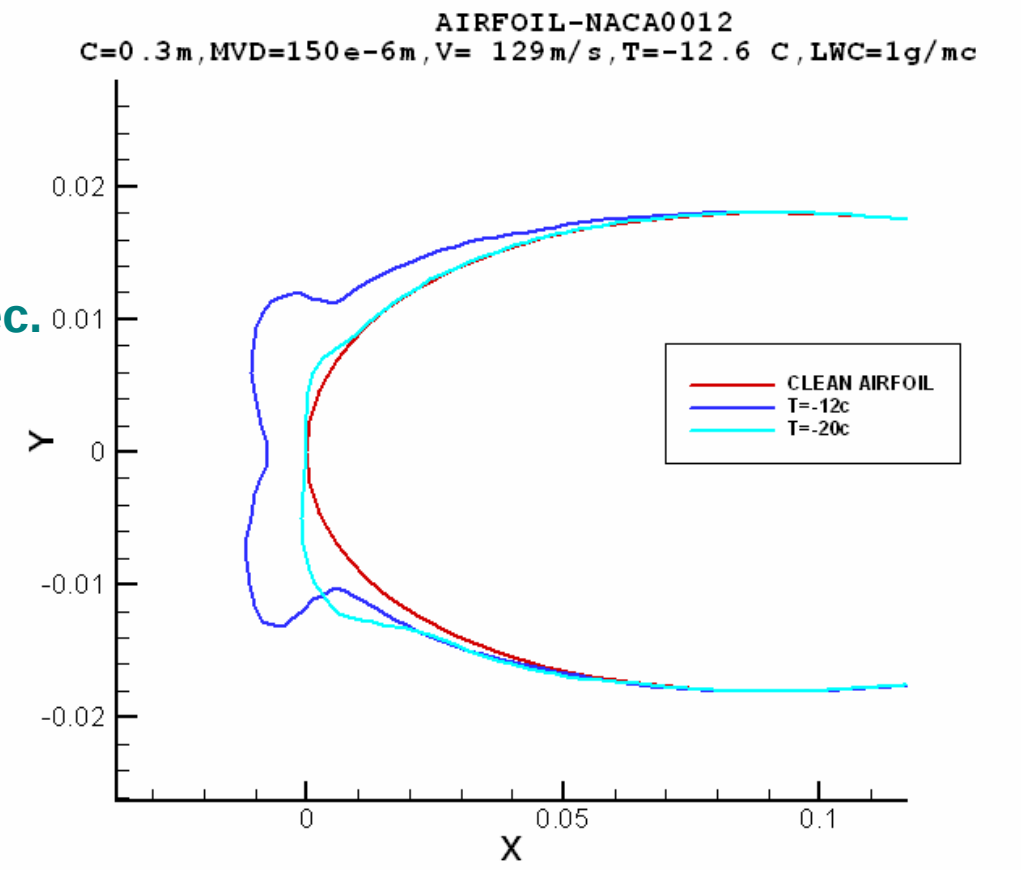
Results- NACA0012 airfoil

- Effect of temperature on ice shapes (CANICE 2D)

Ice Accretion time =120 Sec.
Ice layers = 3



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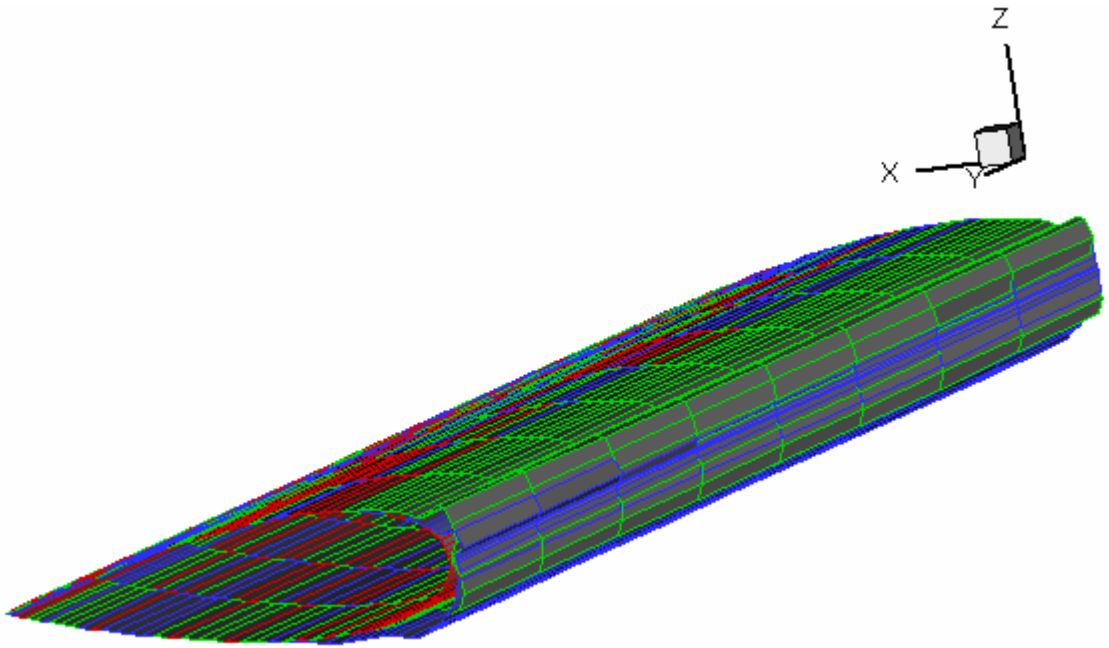
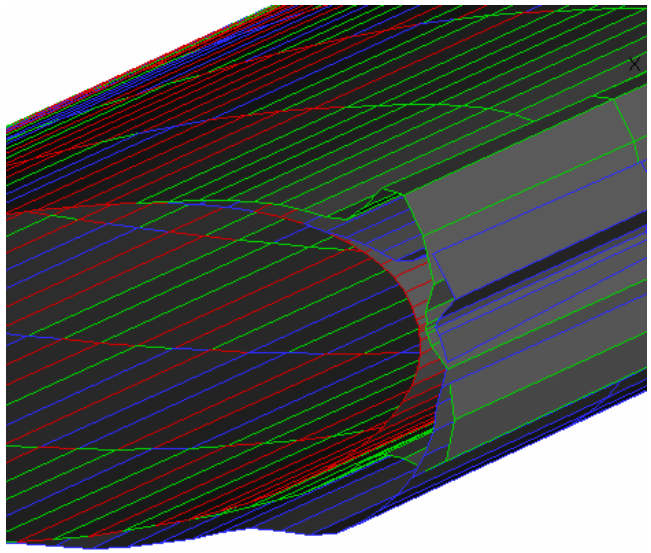
Results- NACA0012 airfoil / wing

- **Clean Wing**
- **Iced wing-AOA= 8deg**
- **Iced wing–AOA= 0deg**

MVD=150 µm, LWC=1.0g/mc





SLD Modeling – MS-317 airfoil / wing

- **Effect of MVD on water collection efficiency**

  MVD=21, 92 µm

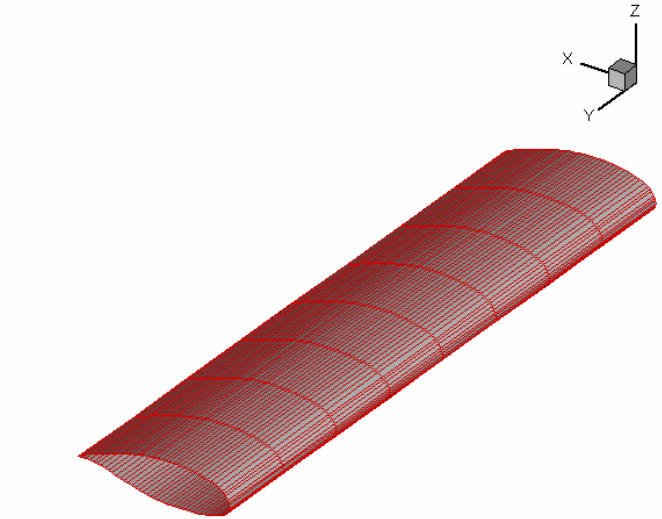
- **Effect of AOA on water collection efficiency**

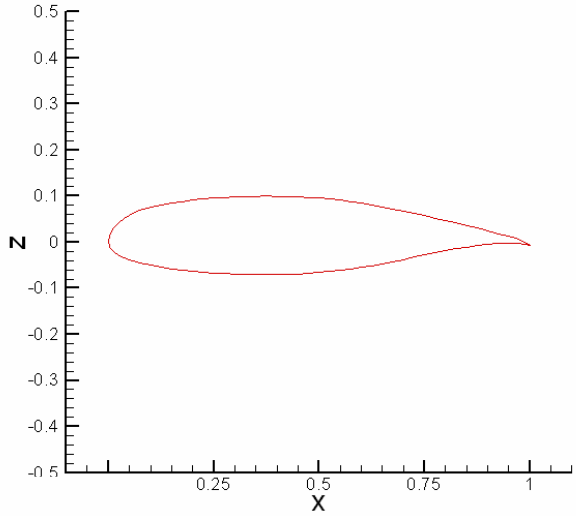
  MVD=21, 92 µm , AOA = 0 , 8 deg.

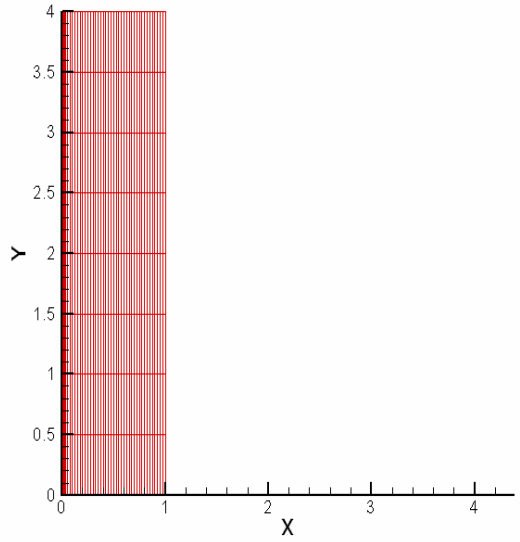
SLD Modeling

- **MS(1)-317 airfoil/wing**

Chord =1m AR =8 Panel No. = 100x8







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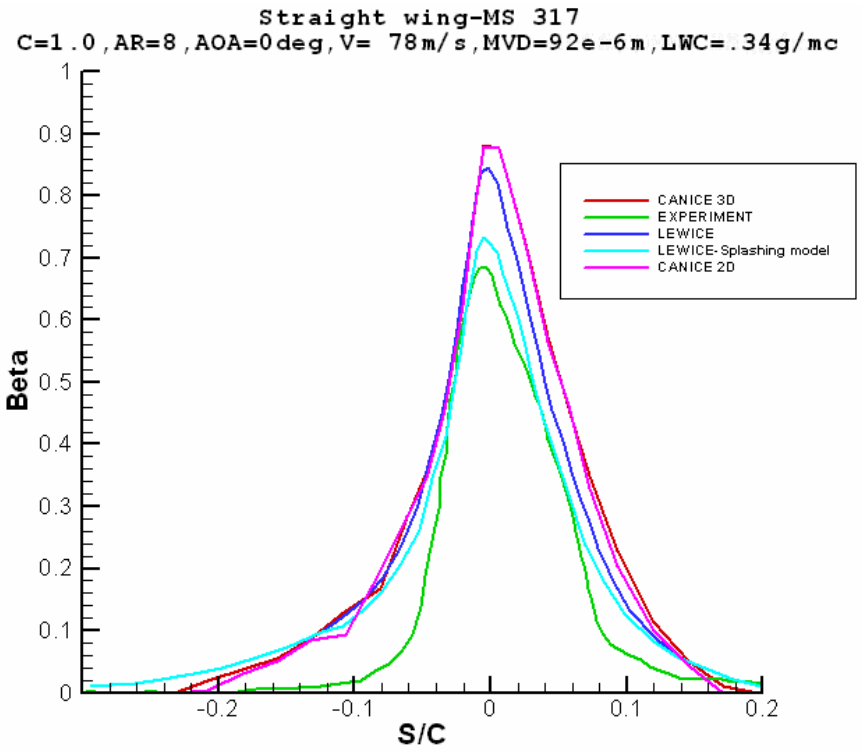
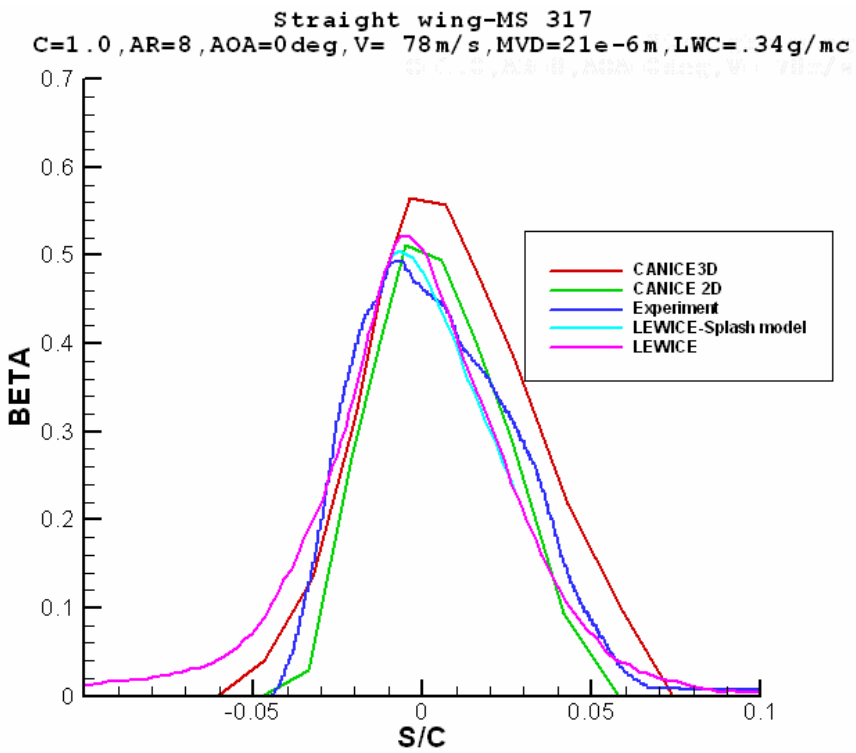
Results – MS-317 airfoil / wing

- **Effect of MVD on water collection efficiency**

CANICE 3D : Y= mid. Span Section

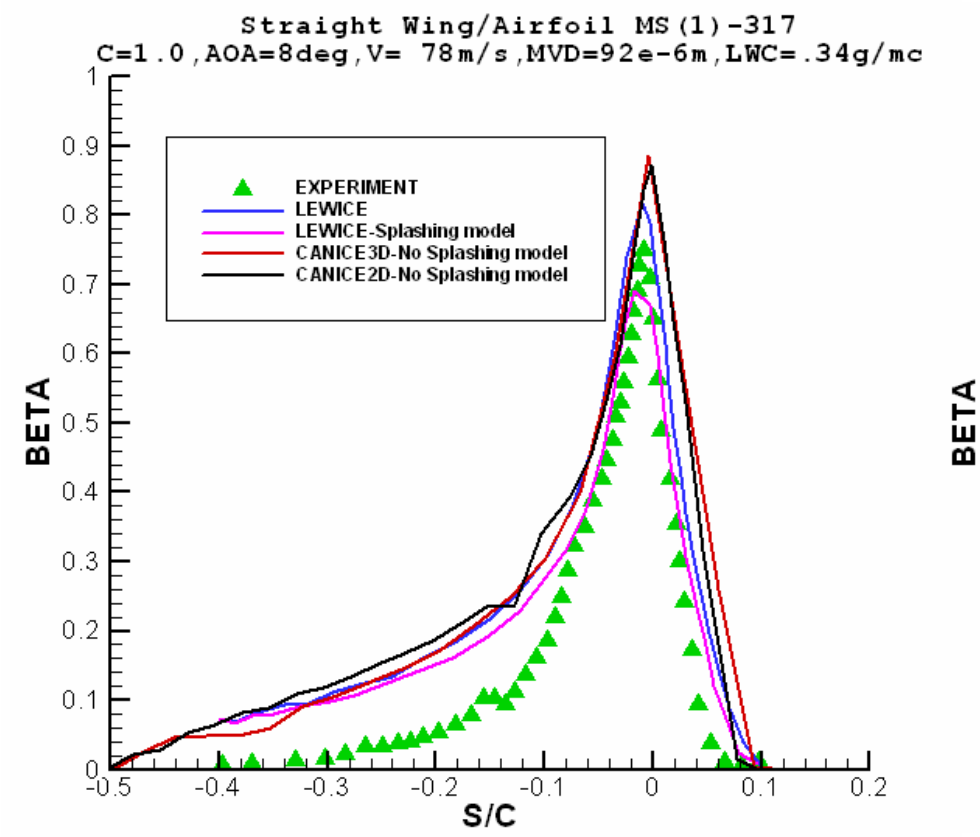


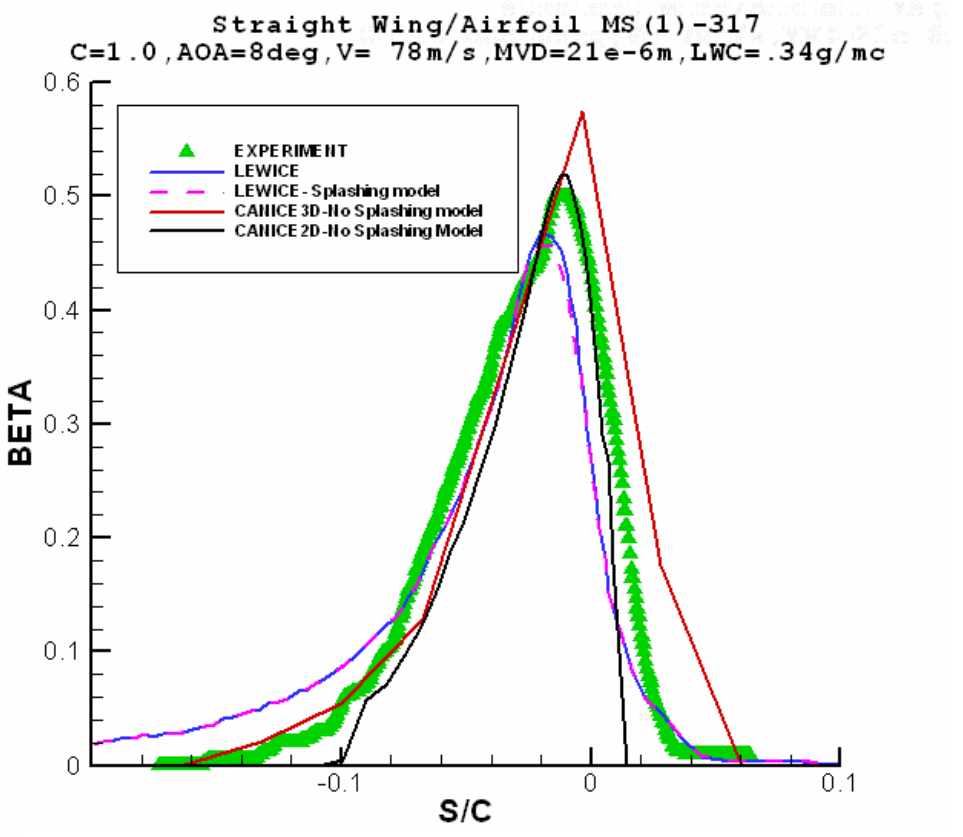
W.B. Wright & M.G. Potapczuk, AIAA-2004-0412



Results – MS-317 airfoil

- Effect of AOA on water collection efficiency





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CONCLUSIONS

- CANICE-2D and CANICE-3D have the (limited) capability of modeling ice accretion in SLD conditions
- Analysis of the effects of SLD on water impingement and ice accretion has been conducted using CANICE-2D and CANICE-3D
- The influence of the main parameters (MVD, LWC, T and AOA) was evaluated and the qualitative results are satisfactory
- Quantitative differences show that the influence of other phenomena which are important in SLD conditions (droplet breakup , droplet splashing, water shedding) should be modeled.

FUTURE WORK

- Further assess the capabilities and the limitations of CANICE-2D and CANICE-3D in SLD conditions and on other configurations
- Implement in CANICE (2 & 3D) and validate semi-empirical models for droplets splashing
- Implement in CANICE (2 & 3D) and validate models for water shedding